

- **Linearity**

A linear system is a system that satisfies the superposition and homogeneity principles. Homogeneity principle states that an output $y(t)$ of an input $x(t)$ must produce an output $ay(t)$ for an input $ax(t)$. Superposition principle states that an output $y_1(t)$ for an input $x_1(t)$ and an output $y_2(t)$ for an input $x_2(t)$ must produce an output $y_1(t) + y_2(t)$ for an input $x_1(t) + x_2(t)$.

- ❖ **Linearity Test**

$$x_1 = [-3 \ -4 \ 2 \ 0 \ 1 \ 4 \ 3 \ 6 \ 3 \ 7]$$

$$x_2 = [2 \ 5 \ -1 \ 7 \ -3 \ 6 \ 12 \ -9 \ 8 \ -4]$$

and

$$x_1 = [9 \ 23 \ 15 \ -10 \ 18 \ 14 \ 5 \ -1 \ 6 \ 11]$$

$$x_2 = [2 \ 5 \ -1 \ 7 \ -3 \ 6 \ 12 \ -9 \ 8 \ -4]$$

- **Causality**

A causal system is a system where the output depends on past and current inputs but not future inputs. This means that the output $y(t_0)$ depends only on the input $x(t)$ for the values of $t \leq t_0$.

- **Time-Invariance**

- ❖ **Time-Invariance Test**

A time-invariant system is a system where a certain input will always give the same output without regarding the time that the input was given to the system.

$$x = [-3 \ -4 \ 2 \ 0 \ 1 \ 4 \ 3 \ 6 \ 3 \ 7]$$

$$x = [5 \ -11 \ 9 \ 2 \ 3 \ -6 \ 0 \ -7 \ 3 \ 10]$$

- ★ **Systems Tested:**

a) $y[n] = nx[n + 2]$

b) $y[n] = x[2n]$

c) $y[n] = 3x[n + 4] + 5$

d) $y[n] = |x[n]|$

e) $y[n] = \sum_{k=1}^n x[k]$

- ★ **Output of Systems Test:**

System 1 passes the property test for a = -4 and b = -4

System 1 passes the property test for a = -3 and b = 3

System 1 passes the property test for a = 1 and b = 5

System 1 passes the property test for a = 3 and b = 1

System 1 passes the property test for a = -1 and b = -2

System 1 passes the property test for a = 3 and b = -4

System 1 passes the property test for a = -4 and b = 3

System 1 passes the property test for a = -2 and b = 1

System 1 passes the property test for a = -2 and b = 2

System 1 passes the property test for a = -2 and b = 2

System 1 passes the property test for a = 5 and b = -5

System 1 passes the property test for a = 0 and b = -4

System 1 passes the property test for a = 2 and b = 5

System 1 passes the property test for a = -5 and b = 0

System 1 passes the property test for $a = 1$ and $b = 2$
System 1 passes the property test for $a = -2$ and $b = 1$
System 1 passes the property test for $a = -3$ and $b = 2$
System 1 passes the property test for $a = 2$ and $b = 0$
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System 4 passes the property test for $a = 5$ and $b = 0$
System 4 does not pass the system property test for $a = 3$ and $b = -2$
System 4 does not pass the system property test for $a = -5$ and $b = 1$
System 4 does not pass the system property test for $a = -2$ and $b = 2$
System 4 does not pass the system property test for $a = 4$ and $b = -4$
System 4 does not pass the system property test for $a = 1$ and $b = 1$
System 4 passes the property test for $a = 0$ and $b = 0$
System 4 does not pass the system property test for $a = 5$ and $b = -3$
System 4 does not pass the system property test for $a = 1$ and $b = 1$
System 4 does not pass the system property test for $a = -5$ and $b = 2$
System 4 does not pass the system property test for $a = 4$ and $b = -1$
System 4 does not pass the system property test for $a = -1$ and $b = -5$
System 4 does not pass the system property test for $a = 1$ and $b = 4$
System 4 does not pass the system property test for $a = -3$ and $b = -4$
System 4 does not pass the system property test for $a = -3$ and $b = 2$
System 4 does not pass the system property test for $a = 3$ and $b = 1$
System 4 does not pass the system property test for $a = 0$ and $b = -2$
System 4 does not pass the system property test for $a = 2$ and $b = 1$
System 4 does not pass the system property test for $a = 2$ and $b = -4$
System 4 does not pass the system property test for $a = 2$ and $b = 2$
System 4 does not pass the system property test for $a = 5$ and $b = 4$
System 4 does not pass the system property test for $a = -4$ and $b = 5$
System 4 does not pass the system property test for $a = -3$ and $b = -3$
System 4 does not pass the system property test for $a = -5$ and $b = -2$
System 4 does not pass the system property test for $a = -2$ and $b = 1$
System 4 does not pass the system property test for $a = -1$ and $b = -3$
System 4 does not pass the system property test for $a = -1$ and $b = -4$

System 4 does not pass the system property test for $a = 4$ and $b = -4$
System 4 does not pass the system property test for $a = 2$ and $b = 3$
System 4 does not pass the system property test for $a = -5$ and $b = -4$
System 4 does not pass the system property test for $a = -5$ and $b = 3$
System 4 does not pass the system property test for $a = -5$ and $b = 2$
System 4 passes the property test for $a = 0$ and $b = 3$
System 4 does not pass the system property test for $a = -2$ and $b = -5$
System 4 does not pass the system property test for $a = -3$ and $b = 2$
System 4 does not pass the system property test for $a = 1$ and $b = 4$
System 4 does not pass the system property test for $a = 3$ and $b = -4$
System 4 does not pass the system property test for $a = 5$ and $b = 3$
System 4 does not pass the system property test for $a = -5$ and $b = 2$
System 4 does not pass the system property test for $a = 0$ and $b = -5$
System 4 does not pass the system property test for $a = -4$ and $b = -5$
System 4 does not pass the system property test for $a = 1$ and $b = -3$
System 4 does not pass the system property test for $a = -4$ and $b = 0$
System 4 does not pass the system property test for $a = 5$ and $b = 1$
System 4 does not pass the system property test for $a = 2$ and $b = -3$
System 4 does not pass the system property test for $a = -3$ and $b = -5$
System 4 passes the property test for $a = 2$ and $b = 0$
System 4 passes the property test for $a = 0$ and $b = 4$
System 4 does not pass the system property test for $a = 5$ and $b = 3$
System 4 does not pass the system property test for $a = -3$ and $b = 2$
System 4 does not pass the system property test for $a = 3$ and $b = 1$
System 4 does not pass the system property test for $a = 4$ and $b = 5$
System 4 does not pass the system property test for $a = 2$ and $b = -5$
System 5 passes the property test for $a = -3$ and $b = -5$
System 5 passes the property test for $a = 5$ and $b = 0$
System 5 passes the property test for $a = 3$ and $b = 0$
System 5 passes the property test for $a = 0$ and $b = -1$
System 5 passes the property test for $a = 4$ and $b = 4$
System 5 passes the property test for $a = 1$ and $b = -2$
System 5 passes the property test for $a = -2$ and $b = -3$
System 5 passes the property test for $a = 2$ and $b = 3$
System 5 passes the property test for $a = 4$ and $b = 3$
System 5 passes the property test for $a = -3$ and $b = 3$
System 5 passes the property test for $a = 1$ and $b = -3$
System 5 passes the property test for $a = -1$ and $b = -1$
System 5 passes the property test for $a = 0$ and $b = 0$
System 5 passes the property test for $a = -2$ and $b = -2$

System 5 passes the property test for $a = 2$ and $b = 5$
System 5 passes the property test for $a = 1$ and $b = 1$
System 5 passes the property test for $a = 3$ and $b = -1$
System 5 passes the property test for $a = -1$ and $b = 0$
System 5 passes the property test for $a = 5$ and $b = -1$
System 5 passes the property test for $a = 2$ and $b = 0$
System 5 passes the property test for $a = 1$ and $b = -5$
System 5 passes the property test for $a = 3$ and $b = 2$
System 5 passes the property test for $a = -3$ and $b = -5$
System 5 passes the property test for $a = 3$ and $b = 1$
System 5 passes the property test for $a = 2$ and $b = 1$
System 5 passes the property test for $a = 3$ and $b = 4$
System 5 passes the property test for $a = 2$ and $b = -4$
System 5 passes the property test for $a = 2$ and $b = -1$
System 5 passes the property test for $a = 2$ and $b = 2$
System 5 passes the property test for $a = 2$ and $b = -5$
System 5 passes the property test for $a = -3$ and $b = -4$
System 5 passes the property test for $a = 5$ and $b = 0$
System 5 passes the property test for $a = 2$ and $b = 2$
System 5 passes the property test for $a = -5$ and $b = -3$
System 5 passes the property test for $a = -2$ and $b = 5$
System 5 passes the property test for $a = -3$ and $b = -3$
System 5 passes the property test for $a = 2$ and $b = 2$
System 5 passes the property test for $a = 2$ and $b = 4$
System 5 passes the property test for $a = 3$ and $b = -5$
System 5 passes the property test for $a = 1$ and $b = 5$
System 5 passes the property test for $a = -4$ and $b = 1$
System 5 passes the property test for $a = 5$ and $b = -3$
System 5 passes the property test for $a = 0$ and $b = -4$
System 5 passes the property test for $a = 3$ and $b = -2$
System 5 passes the property test for $a = -3$ and $b = 5$
System 5 passes the property test for $a = 2$ and $b = 4$
System 5 passes the property test for $a = 2$ and $b = 2$
System 5 passes the property test for $a = 0$ and $b = -3$
System 5 passes the property test for $a = 0$ and $b = 1$
System 5 passes the property test for $a = 4$ and $b = -3$
System 5 passes the property test for $a = 0$ and $b = 3$
System 5 passes the property test for $a = -2$ and $b = 1$
System 5 passes the property test for $a = 2$ and $b = -3$
System 5 passes the property test for $a = 2$ and $b = -5$

System 5 passes the property test for $a = 0$ and $b = 1$
System 5 passes the property test for $a = -5$ and $b = 4$
System 5 passes the property test for $a = 4$ and $b = 3$
System 5 passes the property test for $a = 3$ and $b = -1$
System 5 passes the property test for $a = -4$ and $b = -2$
System 5 passes the property test for $a = 2$ and $b = 5$
System 5 passes the property test for $a = -4$ and $b = 3$
System 5 passes the property test for $a = -5$ and $b = 3$
System 5 passes the property test for $a = 0$ and $b = -5$
System 5 passes the property test for $a = 4$ and $b = -4$
System 5 passes the property test for $a = -4$ and $b = -3$
System 5 passes the property test for $a = -2$ and $b = 1$
System 5 passes the property test for $a = 2$ and $b = 5$
System 5 passes the property test for $a = 5$ and $b = 3$
System 5 passes the property test for $a = -2$ and $b = 5$
System 5 passes the property test for $a = -1$ and $b = -3$
System 5 passes the property test for $a = 1$ and $b = -5$
System 5 passes the property test for $a = -5$ and $b = -4$
System 5 passes the property test for $a = -3$ and $b = 2$
System 5 passes the property test for $a = -1$ and $b = 4$
System 5 passes the property test for $a = -1$ and $b = 4$
System 5 passes the property test for $a = 3$ and $b = 1$
System 5 passes the property test for $a = -4$ and $b = 0$
System 5 passes the property test for $a = 0$ and $b = -1$
System 5 passes the property test for $a = -4$ and $b = -3$
System 5 passes the property test for $a = -2$ and $b = -1$
System 5 passes the property test for $a = -4$ and $b = -2$
System 5 passes the property test for $a = -2$ and $b = 4$
System 5 passes the property test for $a = -2$ and $b = 4$
System 5 passes the property test for $a = -3$ and $b = 3$
System 5 passes the property test for $a = 1$ and $b = -5$
System 5 passes the property test for $a = 2$ and $b = -5$
System 5 passes the property test for $a = 2$ and $b = 4$
System 5 passes the property test for $a = -1$ and $b = 1$
System 5 passes the property test for $a = 1$ and $b = -3$
System 5 passes the property test for $a = 3$ and $b = -2$
System 5 passes the property test for $a = 5$ and $b = -2$
System 5 passes the property test for $a = 0$ and $b = -2$
System 5 passes the property test for $a = -3$ and $b = 0$
System 5 passes the property test for $a = -4$ and $b = -4$

System 5 passes the property test for $a = -4$ and $b = -2$

System 5 passes the property test for $a = 3$ and $b = 0$

System 5 passes the property test for $a = 4$ and $b = 5$

System 5 passes the property test for $a = -2$ and $b = -3$

System 5 passes the property test for $a = 0$ and $b = -2$

System 5 passes the property test for $a = 4$ and $b = -3$

➤ MATLAB CODE OF SYSTEMS

```
%%System a)
for n = 1 : length(x)-2
    y(n) = n * x (n + 2);
end
y(length(x) -1 : length(x)) = 0;

%%System b)
k = length(x)/2;
for n = 1 : k
    y(n) = x (2*n);
end

%%System c)
for n = 1 : length(x)-4
    y(n) = 3 * x (n + 4) + 5;
end
y(length(x) -3 : length(x)) = 0;

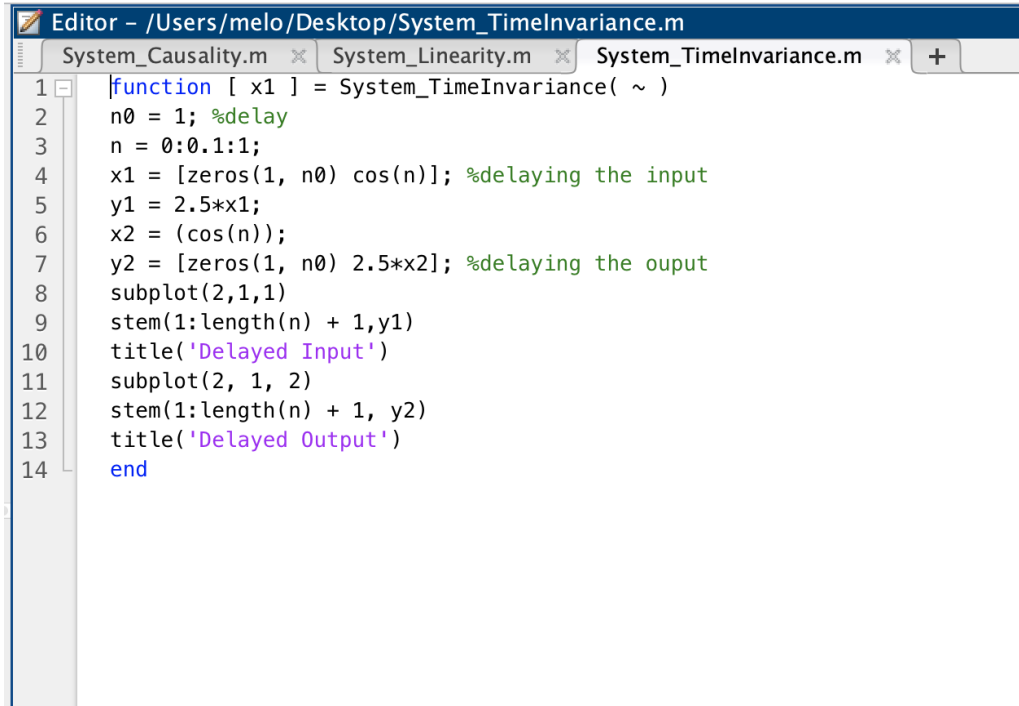
%%System d)
for n = 1 : length(x)
    y(n) = abs(x(n));
end

%%System e)
for n = 1 : length(x)
    y(n) = sum(x(1:n));
end
```


➤ MATLAB CODE OF PARTS 2, 3, 4

```
Editor - /Users/melo/Desktop/System_Causality.m
System_Causality.m System_Linearity.m System_TimeInvariance.m +
1 function [ x ] = System_Causality( ~ )
2 k=2; %delay
3 n=0:2 + k;
4 x = [10 2 5 zeros(1, k)];
5 subplot(411)
6 stem(n, x)
7 xdelay = [zeros(1, k) x(1:3)];
8 subplot(412)
9 stem(n, xdelay)
10 x = x + n.*xdelay;
11 nk = (0:length(n) - 1 + k) - k; %delayed output
12 ydelayed = [xdelay zeros(1, k)] + nk.*[zeros(1, k) xdelay];
13 subplot(413)
14 stem(0:length(ydelayed)-1, ydelayed)
15 n1 = (0:length(n)-1 + k);
16 output = [xdelay zeros(1, k)]+n1.*[zeros(1, k) xdelay];
17 subplot(414)
18 stem(0:length(output)-1, output)
19 end
```

```
Editor - /Users/melo/Desktop/System_Linearity.m
System_Causality.m System_Linearity.m System_TimeInvariance.m +
1 function [ array ] = System_Linearity( ~ )
2 n = -30:30;
3 x1_n = cos(2*pi*0.1*n);
4 x2_n = cos(2*pi*0.4*n);
5 array = [2.2403 2.4908 2.2403];
6 input = [1 -0.4 0.75];
7 y1 = filter(array, input, x1_n);
8 y2 = filter(array, input, x2_n);
9 a = 2;
10 b = -3;
11 x3 = a*x1_n + b*x2_n;
12 y3 = filter(array, input, x3);
13 z = a*y1 + b*y2;
14 p = y3 - z;
15 stem(n, p)
16 end
17
```



```
1 function [ x1 ] = System_TimeInvariance( ~ )
2     n0 = 1; %delay
3     n = 0:0.1:1;
4     x1 = [zeros(1, n0) cos(n)]; %delaying the input
5     y1 = 2.5*x1;
6     x2 = (cos(n));
7     y2 = [zeros(1, n0) 2.5*x2]; %delaying the ouput
8     subplot(2,1,1)
9     stem(1:length(n) + 1,y1)
10    title('Delayed Input')
11    subplot(2, 1, 2)
12    stem(1:length(n) + 1, y2)
13    title('Delayed Output')
14    end
```

References

https://en.wikipedia.org/wiki/Causal_system

[https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Signal_Processing_and_Modeling/Signals and Systems \(Baraniuk et al.\)/02%3A_Introduction to Systems/2.02%3A_Linear Time Invariant Systems](https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Signal_Processing_and_Modeling/Signals_and_Systems_(Baraniuk_et_al.)/02%3A_Introduction_to_Systems/2.02%3A_Linear_Time_Invariant_Systems)

<https://www.tutorialspoint.com/signals-and-systems-linear-and-non-linear-systems>